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FRICTION AND WEAR DEVICES — A SURVEY

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NOTICES

FOREWORD

This report was prepared by Subcommittee on Wear of the American Society of Lubrication Engineers with Mr. R. J. Benzing of the Fluid and Lubricant Materials Branch, Nonmetallic Materials Division, Air Force Materials Laboratory acting as Chairman. The preparation of the report was initiated under Project 7343, "Aerospace Lubricants" Task 734302 "Dry and Solid Film Lubricant Materials."

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ABSTRACT

A summary of a survey conducted on laboratory friction and wear devices is presented. This survey was made by the Subcommittee on Wear of the Lubrication Fundamentals Committee. The survey covered the literature from 1945 to 1965 and uncovered 102 devices using simulative test specimens. The summary presented in this paper includes the original scope of the survey, a summary of the results including characteristics of the 102 devices, and the conclusions drawn by the subcommittee.

INTRODUCTION

A recent survey (1) has uncovered and described over one-hundred different devices used by investigators to study friction and wear under a wide variety of test conditions. This work was performed by the Subcommittee on Wear of the Lubrication Fundamentals Committee of ASLE. Initially the survey involved a review of the literature to uncover the various devices. This literature search was originally designed to include various types of wear devices and later was modified to also include friction test devices but exclude equipment employing actual machine elements (such as gears and bearings) as the test specimens. Each device uncovered in this search was described by the subcommittee and these descriptions were then forwarded to users, designers, and/or manufacturers of the equipment for their comment. The results of this were then compiled in a report presented to the Lubrication Fundamentals Committee on 5 May 1966. The purpose of that report was to compile in one source a description of the various devices. This can serve as a ready reference to anyone interested in information on a wide variety of such test devices. The purpose of this paper is to provide a thumb nail sketch of that report and the original survey that led to the compilation of the report.

Literature Search, Write-ups, and Questionnaire

Before discussing the results of the survey it is best to define the extent of the literature search. It included rigs used with liquids, solids, greases, and gases as well as those employed in dry friction and wear studies. It covered the period from 1945 through 1965. The major sources of information included:

ASLE Transactions

ASME Transactions

Department of Defense Reports

Journal of Applied Physics

Lubrication Engineering

NACA Reports

NASA Reports

Scientific Lubrication

Wear

"Wear and Lubrication Characteristics Mineral Oils and Synthetic Lubricants" a thesis by E. E. Klaus.

"Handbook of Mechanical Wear" edited by Charles Lipson and L. V. Colwell, University of Michigan Press, 1961.

"Proceedings of the Conference on Lubrication and Wear" Institute of Mechanical Engineers, London, 1957.

"Friction and Wear" proceedings of the General Motors Corporation symposium on friction and wear, edited by Robert Davies, Elsevier Publishing Company, 1959.

"Mechanisms of Solid Friction" proceedings of a conference on fundamental mechanisms of solid friction, edited by P. J. Bryant, M. Lavik and G. Salmon, Elsevier Publishing Company, 1964.

To somewhat better define the scope it can be pointed out that over 5000 references were screened in the field of solid lubricants. Even though

the literature search only went back to 1945 there are some references prior to that for those pieces of equipment which were developed earlier but still find wide use today. The Shell Four Ball Wear Tester would be one such piece of equipment.

The information obtained from this literature search was used to prepare brief write-ups of each piece of equipment. These write-ups included sections on description, range of operating conditions, significance, and literature. A schematic of the test specimen configuration was also included. An example of one write-up, that for the Shell Four Ball Wear Tester, is shown in Appendix A. Actually this format is the final one arrived at by the Subcommittee after several initial versions. The minor modifications made throughout the program are not pertinent to this paper.

Under the heading of description, the subcommittee attempted to provide a brief summary of the test device itself. This included such characteristics as geometry, type of drive system, control instrumentation for temperature and atmosphere, loading mechanisms, friction and wear measuring techniques, and any other pertinent information. The degree of completeness of this section and the following one is a function of both the description in the literature and the past knowledge of members of the subcommittee. In some cases the write-ups are very detailed while in others they are skimpy to say the least. More discussion will be devoted to this in the section on Conclusions.

The section on Range of Operating Conditions attempted to include at least levels of temperature, load, speed, and atmosphere. Other information on operational limits was shown when given. The write-up on the

Shell Four Ball Wear Tester shown in Appendix A includes sample size and test time in this section.

The section on Significance is basically the opinion of the Subcommittee. In some cases the significance was reported in the literature and this was included if concurred in by the subcommittee.

The section on Literature is relatively self-explanatory. It does not include all the literature on each piece of equipment but does provide a source for published work.

Having prepared the write-ups, the Subcommittee decided to submit them to people more familiar with the operation of each piece of equipment for additional review and comments. In order to ensure that all comments would be uniform in nature a questionnaire was employed for this solicitation. The questionnaire is shown in Appendix B and the cover letter in Appendix C. As in the case of the write-ups, the questionnaire received several modifications before arriving at this final form. Some of the modifications were made as a result of an initial trial survey to twenty-five people. The main intent of the modifications was to clarify several of the questions and to make it simpler for the responder by requiring less written information. The response to the questionnaire solicitation on the complete set of equipment write-ups was very good with over 75% response. This solicitation also turned up several pieces of equipment for which we had no write-ups. They were subsequently covered but because of time limitations no questionnaires were sent out on these new write-ups.

The final report presented to the Lubrication Fundamentals Committee consisted of each write-up with condensed answers to the questionnaire. In some cases, the responders to the questionnaire suggested modifications

to the write-ups. Final disposition of these comments were made at the discretion of the Subcommittee. As such, the Subcommittee takes full responsibility for the write-ups themselves. In the case of the questionnaires this is another matter. In order to ensure that the Subcommittee did not misinterpret any of the questionnaire replies there was no editing done to them. To save space, the Subcommittee did condense the questionnaire itself to the form shown in Appendix D. The final questionnaire answers then included these condensed headings plus the full written reply of each responder. An example of the format for the Shell Four Ball Wear Tester is shown in Appendix E. To somewhat clarify the above one should compare Appendix D and Appendix E. That portion of Appendix E that is not shown in Appendix D is what the responders sent in. Nothing has been omitted from the responders comments.

Report Summary

The final report included information on 102 different test devices. Those actually covered are tabulated in alphabetical order in Table I. This table also includes the number of a reference where each device has been reported. The actual report of course includes many more references but with a lead on one the reader of this paper should be able to pursue the equipment further if he so desires. Many of the devices listed in this table are quite similar in nature but as far as the authors of this paper can determine they are discrete designs or pieces of equipment. They are not the same device reported by two different investigators under different names. While we believe that most of the times reported in the literature are incorporated we do not believe that all have been included. In addition, there are probably an equal number of devices

Table I

FRICTION AND WEAR TEST DEVICES

No.	Title	Ref.
1	Abrasive Wear Apparatus	2
2	Almen Machine	3
3	Alpha Model LFW-1	4
4	Alpha Model LFW-2	5
5	Alpha Model LFW-3	5
6	Apparatus for Studying Frictions from Loads of Milligrams to Tens of Grams	6
7	Ball on Flat Wear Life Apparatus	7
8	Boeing Company Solid Film Lubricant Test Machine	8
9	Bouncing Ball High Speed Friction Test	9
10	Bowden Leben Apparatus	6
11	Crossed Cylinders Friction and Wear Tester	10
12	Crossed Cylinder Machine (National Engineering Laboratory)	11
13	Cryogenic Fuel Friction Test Apparatus	12
14	Disk and Rider Apparatus	13
15	Erdco One Ball Fatigue Machine	14
16	Falex Lubricant Test Machine	15
17	Flat Rider Sliding on Rotating Ring	11
18	Flat Ring Wear Tester	16
19	Friction and Cold Welding Apparatus	17
20	Friction Apparatus-Vacuum	18
21	Friction-Testing Machine	19
22	Gear Roll Tester	20
23	High Speed Friction Apparatus -- Suspended Ball Type	9
24	High Speed High Temperature Wear and Bearing Evaluation Apparatus (Battelle Memorial Institute)	21
25	High Speed Sliding Friction Test Apparatus	22
26	High Temperature Extreme Pressure Disk Type Lubricant Tester	23
27	High Temperature, High Speed, Rolling Contact Disk Apparatus	24
28	High Temperature High Vacuum Friction and Bearing Apparatus (Southwest Research Institute)	25
29	High Temperature Sliding Contact Apparatus (Battelle Memorial Institute)	26
30	High-Vacuum and Special Environment Slow-Speed Friction and Wear Apparatus	27

Table I - (Contd)

No.	Title	Ref.
31	Hohman A-3 Tester	28
32	Hohman A-6 Tester	29
33	IBM Friction and Wear Machine	30
34	Inclined Plane Static Friction Device	31
35	Interfacial Temperature Apparatus (Rensselaer Polytechnic Institute)	32
36	Kinetic Boundary Friction Apparatus	11
37	Koppers Standard Brake Shoe Type Wear Test	33
38	LFW-4 (Alpha Molykote Corporation)	34
39	Low Speed Friction and Wear Apparatus	35
40	Low Speed Sliding Friction and Wear Test Stand (Mechanical Technology Incorporated)	36
41	Low Velocity Friction Apparatus	37
42	Mark II	38
43	Mark III Pellet Friction Machine	39
44	Mark IV	39
45	Medium and High Temperature Fretting Machines (National Engineering Laboratory)	11
46	Micro Machine for Investigating Combine Rolling and Sliding	40
47	Modified MacMillan Test Machine	41
48	NACA Fret Corrosion Rig	42
49	NACA Friction Apparatus	43
50	NACA High Sliding Velocity Friction Apparatus	44
51	NARMCO Friction Apparatus	45
52	NASA High Temperature Friction Apparatus	46
53	NASA Lubricant Screening Apparatus	47
54	National Engineering Laboratory Six-Spindle Wear Machine	48
55	NEL Rolling Four Ball Machine	11
56	Oscillating Pin on Flat Friction Apparatus (Southwest Research Institute)	49
57	Pin on Ring Machine	50
58	Pin on Disk Machine	51
59	Pin on Drum Machine (Ford Motor Co.)	52
60	Pin on Drum	53
61	Pin on Flat (General Electric Company)	51
62	Precision Rolling Disk Machine (Battelle Memorial Institute)	54
63	Reciprocating Wear Machine	55
64	Reciprocating Wear Tester	56
65	Rods on Rings (Rensselaer Polytechnic Institute)	57
66	Rolling-Disk Machine (Battelle Memorial Institute)	58

Table I - (Cont'd)

No.	Title	Ref.
67	Rotating Anvil-Type Testing Device	59
68	Rotating Beam Fatigue Testing Machine	60
69	SAE Lubricant Test Machine	61
70	Shear Rig (NASA)	62
71	Shell Four-Ball E. P. Lubricant Tester	63
72	Shell Four-Ball Wear Tester	64
73	Sinclair Wear and Friction Apparatus	65
74	Slider and Plate Tester	66
75	Slider Bearing Test Machine	67
76	Sliding Apparatus for PTFE (E. I. DuPont De Nemours and Company)	68
77	Sliding Block Friction Test Facility	69
78	Sliding Friction Apparatus (Air Force Materials Laboratory)	70
79	Sliding Friction Machine (National Research Council, Ottawa, Ontario)	71
80	Sliding Hemisphere on Flat	51
81	Sliding Systems Friction Apparatus	72
82	Spherical Rider Sliding on Flat Rotating Plate	73
83	Static Friction Apparatus	74
84	Stick Slip Machine	75
85	Stick-Slip Test Apparatus	76
86	Three Pins on Flat (M.I.T.)	77
87	Thrust Bearing Machine (Mechanical Technology Incorporated)	78
88	Timken Machine	79
89	T. N. O. Pin on Ring Machine	80
90	Two-Ball Wear Machine	81
91	Ultra High Load Friction Apparatus	82
92	Ultra-High Vacuum Cleavage and Friction Apparatus (General Electric Company)	83
93	Ultra-High Vacuum Friction Apparatus (General Electric Company)	83
94	Ultra-High Vacuum Friction and Wear Apparatus (General Electric Company)	83
95	Ultra-High Vacuum Friction and Wear Tester	84
96	Ultra High Vacuum Friction Rig (Air Force Materials Laboratory)	75
97	Vacuum Friction and Wear Apparatus (NASA)	85
98	Vacuum Rub Shoe Wear Tester (Air Force Materials Laboratory)	86
99	Vibratory Cold Welding Apparatus	87
100	Wear Life Pellet Apparatus	88
101	Wear and Friction Tester (Westinghouse Electric Corporation)	89
102	Westinghouse Friction-Wear Tester	90

TABLE II

SUMMARY OF CHARACTERISTICS OF FRICTION AND WEAR TEST DEVICES

DEVICE NUMBER	GEOMETRY: CURVE ON CURVE	GEOMETRY: CURVE ON FLAT	GEOMETRY: FLAT ON FLAT	TYPE CONTACT: ROLLING	TYPE CONTACT: SLIDING	TYPE MOTION: ONE DIRECTION	TYPE MOTION: OSCILLATORY	SPEED (FEET/MIN): BELOW 1	SPEED (FEET/MIN): MEDIUM	SPEED (FEET/MIN): ABOVE 1000	LOAD: LESS THAN 1 KG	LOAD: LESS THAN 10 KG	LOAD: MORE THAN 10 KG	TEMPERATURE: COOLED: CYROGENIC	TEMPERATURE: COOLED: ORDINARY REFRIG.	TEMPERATURE: NO CONTROL	TEMPERATURE: HEATED: LESS THAN 400 F	TEMPERATURE: HEATED: MORE THAN 400 F	TEMPERATURE: HEATED: MORE THAN 1000 F	ATMOSPHERE: VACUUM	ATMOSPHERE: AIR	ATMOSPHERE: OTHER GASES	TYPE OF LUBRICANTS: LIQUIDS	TYPE OF LUBRICANTS: GREASES	TYPE OF LUBRICANTS: GASES	TYPE OF LUBRICANTS: SOLIDS	TYPE OF LUBRICANTS: NONE
1			■		■	■			■		■	■				■	■				■		■				■
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TABLE II - (Cont'd)

SUMMARY OF CHARACTERISTICS OF FRICTION AND WEAR TEST DEVICES

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47			■		■	■			■				■			■			■		■		■	■		■	■
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which have never been reported in the literature.

A summary of the characteristics of these devices is shown in Table II. The number of the device in this table is consistent with the number in Table I. To assist in using this table it is necessary that the various headings be explained. The following are the criteria for each heading used by the authors in compiling this table:

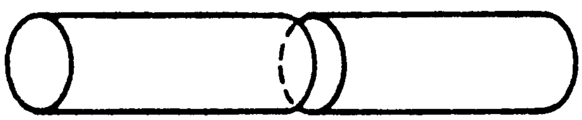
Geometry: Each test specimen surface was classified under one of two basic types - curved or flat. This is a purely arbitrary system as we could have used more complex designations such as sphere, flat, and cylinder as proposed by one person. However, it does provide a simple system of classification. The one basic problem is that it does not define the actual contact geometry, i.e. whether you have point, line, or area contact. No simple system, however, will do this. This can be shown in Figure 1 where the three types of contact geometry are possible with changes in orientation of two cylinders.

Type Contact: This is self-explanatory, and is broken down into either sliding or rolling. In several test devices you can have either sliding or rolling and this is indicated.

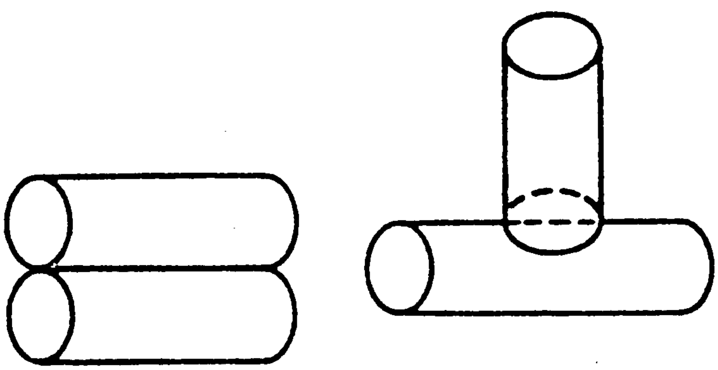
Type Motion: Any device which operated back and forth over the same path whether this was an oscillating cylinder, a pin moving back and forth on a flat, or any other combination of this nature was classified as "oscillatory" in nature. The "one direction" motion was used for those devices which moved in the same direction whether they were tracing the same path or a new path on the test specimen. A phonograph type device is one case where a "one direction" device can trace a new path for example.

FIGURE I

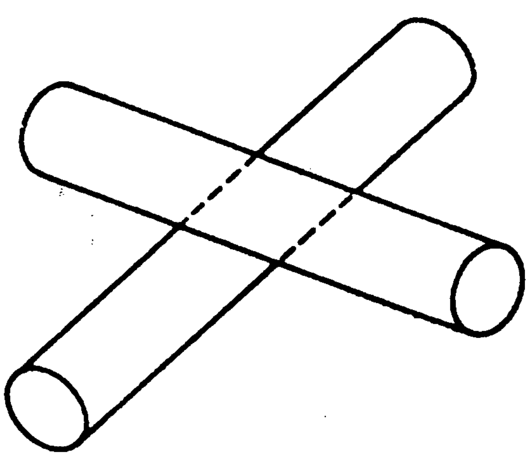
CONTACT GEOMETRY FOR TWO CYLINDERS



AREA CONTACT



LINE CONTACT



POINT CONTACT

Speed: This category and the next, mix the cgs and English systems of measure. The one selected is the one most common in use. The "Medium" range of speed covers 1 to 1000 feet per minute.

Load: There is one factor that needs explanation in this category. That is the fact that several of the devices are checked under more than one of the load categories. In general, where this is done it indicates that the test rig operating conditions have been shown as being capable of both. This particularly applicable to the two categories marked less than 1 kg and less than 10 kg. If a device was indicated to work at 5 kg load it was designated to be in the less than 10 kg category. But if it was classed at .5 kg it was put in the less than 1 kg classification. Both blocks would be checked only if this device was classed as operating from .5 to 5 kg as an example. In general the rule holds throughout the table that where there is duplication of categories or overlap the two will be checked if the device falls in both and cannot be classified in the lower or more restrictive one.

Temperature: Under the cooled classification it was felt that the cryogenic devices should be separated from those employing conventional cooling techniques as the cryogenic rigs generally required special design and insulation not common to the other type. The heated rigs are classified by the maximum bulk temperature that they are run at. No control indicates operation with no heating or cooling provisions. Essentially this is the case where a rig stablizes at some temperature based only on frictional heating. In some cases this was checked as well as a heated block where the test is run without heat applied even though heating units are also used.

Atmosphere: No distinction has been made in the degree of vacuum possible with each rig. This may range from just below atmospheric pressure to 10^{-9} Torr or better. The "other gases" classification does not distinguish the type - i.e. whether they are inert or reactive.

Types of Lubricants

Liquids includes all types from conventional oils to liquid metals.

Greases includes all semi-solids.

Gases can be reactive or inert.

Solids include most solid lubricants such as films, powders, and metal coatings but does not include solids suspended in greases and/or liquids. These types would be included in the liquids and greases categories.

None indicates unlubricated friction and wear test devices.

In examining the table more closely several things become apparent. In general, the majority of the devices appear to be for sliding contacts in unidirectional motion. The type of geometry varies considerably and no generalization can be made here. Moderate speeds in the region of 1 to 1000 fpm appear to be the most common. Load limits are fairly well distributed over the three ranges. From a temperature aspect there are few rigs capable of cooled or below room temperature operation. In the heated category >1000°F seems to be the most popular temperature and this is somewhat surprising as this in general requires more exotic materials of construction. Rigs for use in air are by far the most common. The smaller number of vacuum rigs does not seem to coincide with the larger interest in space studies and points to the fact that a narrower number of researchers is doing this type work.

It is not the intent of this paper to fully analyze the results of this survey but rather to present it for those interested in a ready source of information on test equiment which has been used. The full report itself was designed to provide such a ready reference on a wide variety of test devices. It is felt that as such it should prove of value to anyone engaged in design or operation of friction and/or wear test equipment under lubricated and unlubricated conditions. The new man in the field as well as the experienced researcher can find various factors of concern to him. Certainly the valuable comments provided in response to the questionnaires lend much to the report. Although it is impossible to list them here they have all been singled out in the report to the Lubrication Fundamentals Committee and the authors of thin paper feel deeply indebted to them.

CONCLUSIONS

As noted before, the objective of the survey was to provide a ready reference on various pieces of friction and wear test equipment. The authors of this paper, however, have also drawn the following conclusions based on the work involved in the survey.

(1) Equipment and specimen descriptions as they appear in papers are generally incomplete. In addition to the obvious problem of interpreting results it creates problems for anyone trying to repeat another's work.

(2) Little statistical work has been done in analyzing data and/or repeatability of a piece of equipment.

(3) There are many different test devices but many use the same test specimen configuration.

(4) Most test rigs are designed for general use and only a few attempt to simulate actual operational configurations.

(5) Much of the testing is wasteful as the investigator may not be evaluating what he thinks he is, due to the design of a given rig.

(6) The survey should be kept up-to-date by a review of the literature every ten years. It would not be necessary to go back again to repeat this or any subsequent survey. A literature review and report should be made, however, each ten years for the work reported during that ten year period.

The authors felt that the several of the above conclusions required some elaboration and will attempt to justify their comments in the following paragraphs. Specific examples will not be cited to avoid reflecting

on any individual but nervertheless the conclusions are drawn from actual reported papers.

Quite frequently papers do not adequately describe the test specimens. Such properties as surface finish, hardness, chemical composition, and heat treatment are essential in interpreting results but are not reported. In some cases the equipment was not described sufficiently to even be sure what was the test specimen configuration. Although this was infrequent, there were many cases where associated equipment was not adequately covered. It is realized by the authors that much of this may be due to editorial cuts but the author of a paper should ensure that anyone wishing to reinterpret or repeat his results has sufficient information on the test rig to do so. Equipment and specimen descriptions are less glamorous but do define much of the quality of the data.

Friction and wear work are statistical in nature. Everyone realizes the problem of repeating or reproducing a data point and yet little is done in reporting statistical limits for a piece of equipment. Often data points are averaged and no spread reported. In other cases single points are run to show a certain effect and there have been cases where the known spread of a rig is larger than a difference pointed out to be significant. Authors should define the statistical limits of their rigs so that the reader can know what significance to place on the data.

The third and fourth conclusions are strictly observations and as such are self-explanatory and no further comment is felt necessary.

In some cases the investigator may feel he is investigating a certain parameter but because of the design of his rig he may be studying

something else. As a result, the testing may be wasteful. There are many things which can create such a problem. To illustrate what we mean we would like to take the case of mechanical loading by means of a dead weight lever system. If the investigator has such a system and is not aware of the fact that cyclical vibrations in his system can cause bouncing of the weights or shock loading he may very well invalidate all test data. It is recommended that any person using a new piece of equipment spend considerable time in evaluating its operation and, whenever possible, consult with others who have run similar equipment.

Finally the authors recommend that this survey be kept up-to-date on a ten year basis. There are many new devices and instrumentation techniques being developed so that such a continuing survey should be beneficial. The ten year period is recommended to ensure that the benefit of several papers on a piece of equipment is available. The more published on a rig the more one can assess its capability for providing sound experimental data.

REFERENCES

1. "Friction and Wear Devices - A Survey" a report of the Subcommittee on Wear, Lubrication Fundamentals Committee, American Society of Lubrication Engineers.

2. Rabinowicz, E., Dunn, L. A., Russell, P. G., "The Abrasive Wear Resistance of Some Bearing Steels," Lubrication Engineering, V17 N12, December 1961, pp 587-593.

3. Ellis, E. G., "Lubricant Testing," Scientific Publication Ltd. (London), 1953, pp. 154.

4. Di Sapio, Alfred, "For High Pressures, Low Velocities-Bonded Coatings Lubricate Metal Parts" Product Engineering, 5 Sep 1960 also Alpha Molykote Bulletin #458.

5. Alpha Molykote Bulletin 135.

6. Bowden, F. P., Tabor, D., "The Friction and Lubrication of Solids," Oxford University Press, London, 1950, pp 83.

7. Hubbell, R. D., Private Communication.

8. Hood, J. H., and Campbell, M. E., "Boeing Experience with Bonded Solid Film Dry Lubricants," Wright Air Development Center Technical Report 59-244, 1959, pp 162-164.

9. Bowden, F. P. Tabor, D., "Friction and Lubrication of Solids - Part II," Chapter XXII, Clarendon Press, Oxford, 1964.

10. Milz, W. C., and Sargent, L. B., "Frictional Characteristics of Plastics" Lubrication Engineering 11, No. 5, 1965, pp 313-317.

11. "Proceedings of the Conference on Lubrication and Wear," Institution of Mechanical Engineers, London, 1957.

12. Wisander, D. W., Hady, W. F., and Johnson, R. L., "Friction Studies of Various Materials in Liquid Nitrogen," NACA Tech. Note 4211, 1957.

13. Proceedings of the Symposium on Friction and Wear, Detroit, 1957.

14. "Installation and Operating Instructions 01BF Ball Fatigue Unit," Erdco Engineering Corporation, Addison, Illinois.

15. West, H. L., "The Mechanical Testing of E. P. Lubricants," J. Inst. Petroleum, 32, 1946, pp. 206-229.

16. Steijn, R. R., "Sliding Wear and Metal Transfer Under Unlubricated Conditions" Trans. ASME Journal of Basic Eng., Vol. 81, March 1959, pp 67-78.

17. Moeller, C. E., Bossert, J., Noland, M., "Cold Molecular Welding Study in Ultra-High Vacuum," NASA Report NAS9-3623, 19 November 1965.

18. Hopkins, V., Gaddis, D., Kobett, D., and Hughes, R., "Research on Bearing Lubricants for use in a High Vacuum," Midwest Research Institute Annual Summary Report, 22 Feb. 1961-22 March 1962, Project No. 2492-E.

19. Weil, R. and Paquin, R. A., "An Electron Microscopic Study of Friction and Wear," Wear, 4, N 2, March/April 1961, pp. 123-136.

20. E. G. Jackson, C. F. Muench and E. H. Scott, "Evaluation of Gear Materials Scoring at 700°F," ASLE Trans., 3, No. 1, 1960, pp. 69.

21. Sibley, L. B., Allen, C. M., "Friction and Wear of Refractory Materials at High Sliding Velocities and Temperature," ASME Spring Symposium, May 8-10, 1961; and Wear, Vol. 5, 1962, pp. 312-329.

22. Hopkins, Vern, et al., "Development of New and Improved High Temperature Solid Film Lubricants," ML-TDR-64-37, Part II.

23. Hopkins, Vern, "Development of High Temperature Extreme Pressure Lubricant Tester," Lubrication Engineering, November, 1962.

24. Orcutt, F. K., Krouse, H. H., Allen, C. M., "The Use of Free Energy Relationships in the Selection of Lubricants for High-Temperature Applications," Wear, 5 (1962) p. 345.

25. Brown, R. D., Burton, R. A., and Ku, P. M. "Friction and Wear Characteristics of Cermets at High Temperature and High Vacuum," ASLE Transactions, 5, 1962, pp 24-31.

26. Amateau, Maurice F., et al, "Development of Lubricants for Positive-Displacement Power Sources from 1200°F to 1500°F," ASD Technical Report 61-478, October 1961.

27. Kissel, J. W., Glaeser, W. A., and Allen, C. M., "Frictional Behavior of Sodium-Lubricated Materials in a Controlled High-Temperature Environment," Wear, V. 5, N. 6, Nov-Dec 1962, pp 446-457.

28. Stupp, Bernard C., "Molybdenum Disulfide and Related Solid Lubricants," Lubrication Engineering, 14 No. 4, 1958, pp 159-163.

29. Stupp, B., and Wright, J., "Dry Film Lubricants at Elevated Temperatures" 1963 ASLE Aannual Meeting, New York Also Lubrication Engineering 19, No. 11, November 1963, p. 463.

30. Bayer, R. G., et al, "A Note on the Application of the Stress Dependency of Wear in the Wear Analysis of an Electrical Contact," Wear 7, 1964, pp. 280-287.

31. White, Hobart S., and Sei, Dino, "Static Friction Tests with Special Lubricants," Scientific Lubrication 3, No. 9, September 1951, pp 15.

32. Ling, F. F., and Simkins, T. E., "Measurement of Point-Wise Juncture Conditions of Temperature at the Interface of two Bodies in Sliding Contact," ASD-TDR-62-434, October 1962.

33. Taber, R. D., and Robbins, F. A., "Teflon Based Piston Rings for Non-lubricated Applications". Mechanical Engineering, Sep. 1957, pp 838-9.

34. Sonntag, A., "Press Fit Test Picks Solid Lubricants for Extreme Pressures," Product Engineering, June 21, 1959.

35. Petterson, M. B., and Johnson, R. L., "Friction Studies of Graphite and Mixtures of Graphite, Several Metallic Oxides and Salts at Temperature of 1000°F,"NASA Technical Note 3657.

36. Murray, S. F., and Petterson, M. B., "Evaluation of Moulded Phenolics as Oil Lubricated Bearing Materials," ASME Winter Annual Meeting Philadelphia 17-22 November 1963.

37. Haviland, M. L., Rodgers, J. J., "Friction Characteristics of Automatic Transmission Fluids as Related to Transmission Operation," Lubrication Engineering, V17, No. 13, March 1961, pp 110-117.

38. Lavik, M. T., "High Temperature Solid Dry Film Lubricants," WADC Technical Report 57-455, 1958.

39. Lavik, M. T., et al., "Ceramic Bonded Solid Film Lubricants," WADD TR 60-530, Part I (September, 1960).

40. Benedict, G. H., and Kelley, B. W., "Instantaneous Coefficients of Gear Tooth Friction," ASLE Transaction 4, No. 1, April 1961.

41. Crump, R. E., "Recent Developments in Solid Film Lubricants," in "Proceedings of Air Force-Navy-Industry Conference on Aircraft Lubricants," Wright Air Development Center Technical Report 57-93, June 1957.

42. Godfrey, D., and Bisson, E. E., "Effectiveness of Molybdenum Disulfide as a Fretting Corrosion Inhibitor," NACA TN 2180, 1950.

43. Sliney, H. E., and Johnson, R. L., "Bonded Lead Monoxide Films as Solid Lubricants for Temperatures up to 1250°F," NACA RM E57B15, pp 3, 17.

44. Bisson, Edmond E., "Friction Wear and Surface Damage of Metals as Affected by Solid Surface Film in Handbook of Mechanical Wear," Edited by Charles Lipson and L. V. Colwell, University of Michigan Press, Ann Arbor, 1961, p. 35.

45. Narmco Proposal 100-2494, "Development of Solid Lubricant Films," Sep 1965.

46. Loomis, William R., "Evaluation of Five Bearing - Separator Materials and Polyphenyl Ether Lubricants for Use in Space Power Generation Systems," NASA Technical Note TN D-2663, March 1965.

47. Sliney, H. E., "Lubricating Properties of Some Bonded Fluoride and Oxide Coatings for Temperatures to 1500°F," NASA Technical Note D-478, 1960.

48. Milne, A. A., "Experiments on the Friction and Endurance of Various Surface Treatments Lubricated with Molybdenum Disulfide," Wear, 1, (1957/58), pp 92-103.

49. Brown, R. D., and Burton, R. A., "Fundamental Mechanisms of Lubrication in Space Environment," AFML-TR-65-37, May 1965.

50. Welsh, N. C., and Watts, P. E., "The Wear Resistance of Spark Hardened Surfaces," Wear, 5, No. 4, July/Aug. 1962, pp 289-307.

51. Petterson, M. B., "Investigation of Solid Film Lubricants and Sliding Contacts at Temperatures Above 1000°F," AEC Report APEX-569, 1960.

52. Cocks, M., "Wear Debris in the Contact Between Sliding Metals," J. Applied Physics, 29, No. 11, 1958, pp. 1609-1610.

53. Crook, A. W., "Some Studies of Wear and Lubrication," Wear, 2, No. 5, August 1959, pp. 364-393.

54. Bell, J. C., Kannel, J. W., and Allen, C. M., "The Rheological Behavior of the Lubricant in the Contact Zone of a Rolling Contact System," Paper 63 Lub-8, ASLE-ASME Lubrication Conference, Rochester, N. Y., October 1963.

55. Webber and Milne, "The Use of Strain Gauges in the Measurement of Frictional Forces," Proc. VII the Int. Congress of Applied Mechanics 4, pp. 311.

56. Heath, H. H., Phillips, K. F., "An Investigation Into Sliding Bearings Suitable for a CO_2 - Cooled Nuclear Reactor," Wear 3, (1960), pp. 358-373.

57. Ling, F. F., "Surface Temperature at Sliding Interfaces in Vacua and Metal Adhesion," ML-TDR-64-97, March 1964.

58. Schlosser, A., "Development of Gas-Entrained Powder Lubricants for High-Speed and High-Temperature Operation of Spur Gears," Progress Report No. 3, Contract AF 33(657)-8625, 1 June 1963.

59. Boyd, John, Robertson, B. P., "The Friction Properties of Various Lubricants at High Pressures," ASME Transactions, Vol. 67, No. 1, 1945, pp. 51-59.

60. McDowell, J. R., "Fretting Corrosion Tendencies of Several Combinations of Materials," ASTM STP144, 1953, pp. 24-39.

61. West, H. L., Journal Institute Petroleum, 32, 1946, pp. 206.

62. Petterson, M. B., and Johnson, R. L., "Factors Influencing Friction and Wear With Solid Lubricants," Lubrication Engineering 11, No. 9, 1955, pp 326.

63. Boerlage, G. D., "Four-Ball Testing Apparatus for Extreme Pressure Lubricants," Engineering, 136, 1933, pp. 46.

64. Howlett, J., "Film Lubrication Between Spheroid Surfaces with Application to the Theory of the Four-Ball Machine," J. Appl. Phys., 17, 1964, pp. 137.

65. Dorinson, A. Broman, V. E., "Extreme-Pressure Lubrication and Wear, The Influence of Contact Stress on Metallic Wear," ASLE Trans. V3, No. 2, Oct. 1960, pp. 165-175.

66. Fitzsimmons, V. G., Pickett, D. L., Militz, R. O. and Zisman, W. A., "Dimethyl-Silicone-Polymer Fluids and Their Performance Characteristics in Hydraulic Systems," ASME Trans. 68, 1946, pp. 361-369.

67. Roach, A. E., Goodzeit, C. L., Hannicult, R. P., "Scoring Characteristics of Thirty-Eight Different Elemental Metals in High Speed Sliding Contact With Steel," Trans. ASME 78 (1956), pp. 1659-1667.

68. Steijn, R. P., "The Sliding of PTFE on PTFE," ML-TDR-64-303, December 1964.

69. Kellogg, L. G., "Developments in High-Temperature Ultrahigh Vacuum Friction Studies," 1965 ASLE Conference.

70. Liu, Tung, "Sliding Friction of Copper," Wear 7, 1964, pp. 163-174.

71. Smith, F. W., "Lubricant Behavior in Concentrated Contact Systems - The Castor Oil-Steel System," Wear, 2, No. 4, 1959, pp. 250-263.

72. Rush, W. F., Krueger, R. H., "The Frictional Behavior of Materials and Synthetic Lubricants in Sliding Systems," ASLE Transactions 7, April 1964, p. 197.

73. Kingsbury, E. P., "Solid Film Lubricants at High Temperatures," ASLE Transactions, V. 1, No. 1, April, 1958, pp. 121-123.

74. Levine, E. C., and Petterson, M. B., "Formation of Sulfide Films on Steel and Effect of such Films on Static Friction," NACA TN 2460, 1951.

75. Liu, Tung, Air Force Materials Laboratory, Verbal Communication.

76. Wolf, C. H., "Stick-Slip and Machine Tools," 1965 ASLE Conference.

77. Rabinowicz, E., and Imai, M., "Frictional Properties of Pyrolitic Boron Nitride and Graphite," Wear, 7, No. 3, 1964, pp. 298-300.

78. Murray, S. F., and Petterson, M. B., "Evaluation of Molded Phenolics as Oil Lubricated Bearing Materials," ASME Winter Annual Meeting. Philadelphia 17-22 November 1963.

79. West, H. L., "The Mechanical Testing of E. P. Lubricants," Journal Institute of Petroleum, 32, 1946, pp. 206-229.

80. de Gee, A. W. J., and Zaat, J. H., "Wear of Copper Alloys Against Steel in Oxygen and Argon," Wear, 5, No. 4, 1962, pp. 257-274.

81. Lane, T. B., "Scuffing Temperatures of Boundary Lubricant Films," British J. Appl. Phys. Supplement No. 1, Physics of Lubrication Institute of Physics, 31, 1951, pp. 35-38.

82. Demorest, K. E., Whitaker, A. F., "The Effects of Various Lubricants and Base Materials on Friction at Ultra High Loads," unpublished as of October, 1965.

83. Haltner, A. J., "Friction and Wear Characteristics of Materials Under Ultra-high Vacuum and High Temperature Conditions," AFML-TR-66-26, March 1966.

84. Hopkins, Vern, et al, "Development of New and Improved High Temperature Solid Film Lubricants," ML-TDR-64-37, Part II.

85. Buckley, Donald H., and Johnson, Robert L., "Mechanism of Lubrication for Solid Carbon Materials in Vacuum to 10^{-9} Millimeter of Mercury," ASLE, Transactions, Vol 7, No. 1, 1964, pp. 91-100.

86. Wieser, L. E., "Design Modification of Friction Test Rig for High Vacuum and Elevated Temperature Operation," ML-TDR-64-261, October 1964.

87. Bryant, P. J., Gosselin, C. M., Langley, W. W., "Extreme Vacuum Technology Including a Pressure Calibration Study," Summary Report, Contract NASA-63(06), 1965.

88. Gaddis, D., Hopkins, V. "Research on Bearing Lubricants for Use in High Vacuum," Annual Summary Report, 1964, Contract NAS 8-1540.

89. Bowen, P. H., "Dry Lubricated Bearings for Operation in Vacuum," ASLE Transactions, V. 5, N. 2, November 1962, pp. 315-326.

90. Boes, D. J. and Bowen, P. H., "Friction-Wear Characteristics of Self-Lubricating Composites Developed for Vacuum Service," ASLE Transactions 6, 1963, pp. 192-200.

APPENDIX A

SHELL FOUR-BALL WEAR TESTER

Description

This apparatus, like the Shell Four-Ball E.P. Lubricant Tester, consists of four one-half inch diameter steel (usually 52100) balls in the configuration of an equilateral tetrahedron. The upper ball rotates under prescribed conditions of loads and speeds, and rubs against the three lower balls which are held stationary. The lubricant is contained in a cup surrounding the four-ball assembly. Wear is measured by determining the wear scar diameter generated on the three lower balls. This test is generally used with liquid lubricants although some investigations have been conducted using greases and solid lubricants. Thermostatic controls are provided for controlling the temperature of the lubricant in the cup which surrounds the test specimens. Load is applied by dead weights through a lever arm system. Friction may be determined either by visual observation of the deflection of a spring system or through a strain gage type arrangement. Modification of specimens can be made to permit study of wear of materials of interest. An adaptor holds three small disks (1/4" diam. x 1/8" thick) of the material in a position so that the rotating ball is in

contact with the three disks. Some units have been modified to provide various blanket atmospheres. In another version, the three lower balls are allowed to rotate inside a cylindrical cup, thus permitting study of rolling friction and wear.

Range of Operating Conditions

Load:	0.1 to 50 Kg
Speed:	600, 1200 and 1800 rpm
Temperature:	To 230°C (446°F)
Atmosphere:	Air
Sample:	10 ml per test (100 to 150 ml for complete wear data)
Time:	One to two hours

Significance:

This unit is generally felt to operate in the boundary region of lubricant behavior. It is a well known bench test and though no direct correlation is considered to exist with actual equipment use, it is frequently used in comparing lubricants. Important factors in the study of lubricants are speed, load, time and temperature of test, and character of the lubricant.

Literature

1. Cosgrove, S. L., Sibley, L. B., and Allen, C. M. "Evaluation of Dry Powdered Lubricants at 1000°F in a Modified Four-Ball Wear Machine," ASLE Trans., 2, No. 2, 1960, pp. 219.

2. I-Ming Feng, "A New Approach in Interpreting the Four-Ball Wear Results," Wear, 5, No. 4, 1962, pp. 275.

3. Anon. "Instruction Manual for Shell Four-Ball Lubricant Tester," Precision Scientific Co., Chicago, Ill.

4. Howlett, J., "Film Lubrication Between Spheroid Surfaces with Application to the Theory of the Four-Ball Machine," J. Appl. Phys., 17, 1964, pp. 137.

5. Larsen, R. G., "The Study of Lubrication Using the Four-Ball Type Machine," Lubrication Engineering, 1, 1945, pp. 35

6. Larsen, R. G., and Perry, G. L., "Investigation of Friction and Wear Under Quasi-Hydrodynamic Conditions, Trans Am. Soc. Mech. Engrs., 67, 1945, pp. 45.

7. Davey, W., "A New Method for Presentation of Test Results on the Four-Ball Machine," J. Inst. Petroleum, 33, 1947, pp. 574.

8. Anon. "Manual for Shell Four-Ball Wear Tester," Roxana Machine Works, St. Louis, Missouri.

APPENDIX B

NUMBER (For use by the Subcommittee on Wear): __________.

QUESTIONNAIRE

Please return one copy and you may retain one copy for your files.

NAME: ______________________________ MAILING ADDRESS: ____

1. Are you the manufacturer ______, original designer ______, and/or user ______?
2. Is this device covered by patents? Yes ______, No ______, Unknown ______.

   If known, list Patent Number ____.
3. With what types of lubricants have you used this equipment?

   Liquids ______, Greases ______, Solids ______, Gases ______, No lubricants ______.
4. What is the sample size of lubricant required for conducting one single test run in cc, gm, ml, cfm, inches (thickness), etc.?

   Greseas ____________________________

   Liquids ____________________________

   Solids ____________________________

   Gases ____________________________

   Dry Film ____________________________

5. Over what range of conditions have you used the equipment? Please indicate how accurately the conditions were controlled, if possible.

Load: ________psi, or ________pounds applied.

Speed: ________rpm, or ________fpm.

Temperature: ________° to ________°F.

Pressure range: ________ to ________.

Test element materials: ____________________
(name)
on ____________________.

Atmosphere: Air ____________________

Nitrogen ____________________

Other Gases (name): ____________

____

6. In your experience, what is the effect of the following factors on the friction and wear results obtained with this equipment? Please indicate changes in effects when used as a friction or wear device by checking where applicable.

Test element surface roughness Friction: None____ Small____ Intermediate____ Large____. No experience____.
Wear: None____ Small____ Intermediate____ Large____. No experience____.

Test element temperature Friction: None____ Small____ Intermediate____ Large____. No experience____.
Wear: None____ Small____ Intermediate____ Large____. No experience____.

Test element materials Friction: None____ Small____ Intermediate____ Large____. No experience____.
Wear: None____ Small____ Intermediate____ Large____. No experience____.

(6. continued)

Test element load	Friction:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.
	Wear:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.
Test element speed	Friction:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.
	Wear:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.
Test element motion	Friction:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.
	Wear:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.
Other factors (name)	Friction:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.
	Wear:	None_____ Small_____ Intermediate_____ Large_____. No experience_____.

When warranted, please give additional comments on the effect of the factors in number 6 above:

a. Test element surface roughness:

b. Test element temperature:

c. Test element load:

d. Test element motion:

(6. continued)

e. Test element speed:

f. Test element materials:

g. Other factors:
(name)

7. Indicate your experience with this unit relative to the following:

a. Correlation with data from other test and actual operating equipment: Yes_______ No _______.

If yes, indicate what other equipment and give comments.

b. Statistical reproducibility of data: Yes _______ No _______.

If yes, indicate how determined and degree of reproducibility.

(7. continued)

c. Are there any special techniques you use for data analysis? Yes _______ No _______.

If yes, please describe.

d. List advantages and/or disadvantages in use of this equipment.

e. Have you used this equipment to simulate a specific application? Yes _______ No _______.

If yes, indicate the specific application.

8. Please list other publications which give additional information on the equipment or data obtained with it.

9. Do you contemplate any modifications to the equipment? Yes_______ No _______.

If yes, describe the contemplated changes.

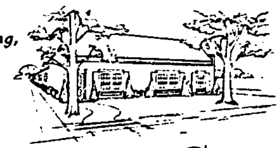
10. Preferred Equipment Designation: ___________________________________.

11. Are there other units in your laboratory which should be covered in this survey? Yes_______ No _______.

If yes, what are they, where has information been reported on them, and can you provide a copy of it?

APPENDIX C

New ASLE headquarters building, near Chicago's O'Hare Airport



American Society of Lubrication Engineers

Publishers of LUBRICATION ENGINEERING • ASLE TRANSACTIONS

REPLY TO: AFML(MANL)
W-PAFB, Ohio 45433

Dear Sir:

We need your help. The survey on wear-measuring equipment that this subcommittee of ASLE is conducting will gather in one place widely-scattered pieces of information about many wear-measuring devices. Our intention is to publish it, and to make it available to researchers who will be responsible for choosing a particular item of equipment for a new experimental program.

We are enclosing a brief description of one piece of equipment to indicate what we think will be most useful to people in the field.

Specifically, what you can do for use involves two things:

a. Since you manufacture or use this equipment, you are in an excellent position to comment on our description of it. Would you tell us what you think of this description?

b. Would you also fill out the questionnaire?

We will give you full credit where warranted for whatever you contribute to this survey. The successful completion of our work will be a giant step forward for all of us.

Sincerely,

R. J. BENZING

FOR THE SUBCOMMITTEE ON WEAR
V. Hopkins
M. Petronio
F. Villforth

1 Encl
Questionnaire

APPENDIX D

CONDENSED
QUESTIONNAIRE ANSWERS

1. A reply from ____.

2. Patented (with number if available)
   Not patented)   Use one of 3.
   Patent Status Unknown)

3. Used with ____.

4. Single test sample size:

5. Range of conditions employed:

6. Effect of factors:

   Comments:

7. Experience:

   a. Correlation -

   b. Reproducibility -

   c. Data analysis techniques -

   d. Advantages and/or disadvantages -

   e. Simulation of application -

9. Equipment modifications:

APPENDIX E

CONDENSED QUESTIONNAIRE ANSWERS

Questionnaire No. 1

1. Reply from a user.

2. Patent status unknown.

3. Used with liquids, greases, solids, and no lubricants.

4. Single test sample size:

Greases:	5 grams
Liquids:	30 cc

5. Range of condition employed:

Loads:	5 to 40 Kg
Speed:	600, 1200, 1800 rpm
Temperature:	RT to 400°F
Materials:	52100 steel balls
Atmosphere:	Air

6. Effect of factors:

	Friction	Wear
a. Test element surface roughness	No experience	No experience
b. Test element temperature	Intermediate	Intermediate
c. Test element load	Small	Large
d. Test element motion	Intermediate	-
e. Test element speed	Large	Intermediate
f. Test element material	No experience	No experience
g. Other	-	-

7. Experience:

   a. Correlation - No. Used only as an indication of lubricant performance.

   b. Reproducibility - None.

   c. Data analysis techniques - None.

   d. Advantages and/or disadvantages - Frictional heat is severe. Contact should be intermittent.

   e. Simulation of application - None.

9. Equipment modification:

   Yes. Perhaps making one into a rolling 4-ball.

Questionnaire No. 2

1. Reply from a user.

2. Patent status unknown.

3. Used with liquids, greases and solids.

4. Single test sample size:

Greases:	10 ml
Liquids:	10 ml
Solids:	1.5 g

5. Range of conditions employed:

Loads:	5 to 50 Kg
Speeds:	600 - 3600 rpm
Temperature:	75° to 1000°F
Materials:	Any material amenable to fabrication in the form of 1/2 inch balls on like or dissimilar materials.
Atmosphere:	Air, nitrogen, argon.

6. Effect of factors:

	Friction	Wear
a. Test element surface roughness	No experience	No experience
b. Test element temperature	Large	Large
c. Test element load	Large	Large
d. Test element motion	No experience	No experience
e. Test element speed	Small	Intermediate
f. Test element materials	Large	Large
g. Other	-	-

Comments: None.

7. Experience:

a. Correlation - None.

b. Reproducibility - None.

c. Data analysis techniques - None.

d. Advantages and/or disadvantages -
   1. Rapid method for determining relative merits of fluids as boundary lubricants.
   2. Rapid method for evaluating relative merits of solid lubricants delivered as powders in a gas stream.

e. Simulation of application - None.

Questionnaire No. 2 - (Cont'd)

9. Equipment modification - None.

Questionnaire No. 3

1. Reply from a user.

2. Patent No. 2, 019,948.

3. Used with liquids, and greases.

4. Single test sample size:

Greases:	10 cc or less
Liquids:	10 cc or less

5. Range of conditions employed:

Loads:	0 - 110 pounds
Speeds:	600 - 1800 rpm
Temperature:	Room to 500°F
Pressure:	Atmospheric
Atmosphere:	Air

6. Effect of factors:

	Friction	Wear
a. Test element surface roughness	Intermediate	Intermediate
b. Test element temperature	Intermediate	Intermediate
c. Test element load	Large	Large
d. Test element motion	See comment	See Comment
e. Test element speed	Small	Small
f. Test element materials	Large	Large
g. Other	See Comment	See Comment

Comments:

a. Surface Roughness: Commercial 1/2" diameter steel balls probably do not differ in roughness enough to be significant. However, composition and Beilby layer were determined long ago to be factors in reproducibility of 4-Ball EP tests.

b. Temperature: Affects different antiwear additives differently.

c. Load: Of the variables, speed load, temperature and duration, load has the greatest effect.

d. Motion: Machine is limited to sliding.

e. Speed: Not too critical. Very little difference noted in many cases for 600 to 1200 rpm change.

f. Materials: A.I.S.I. 52100 steel normally, but 1/2" diameter balls of various compositions are commercially available. Also, can use 1/16" sheet stock for three lower test pieces.

g. Other: A properly constructed spindle should have less than 0.0005" TIR Dynamic balance as speeds are increased becomes important.

7. Experience:

a. Correlation - Limited.

b. Reproducibility - Dependent upon choice of lubricant and surfaces. Conditions leading to incipient seizure often show poor repeatability.

c. Data analysis techniques - Use flywheel on spline to extend coasting time. Plot friction vs speed with x-y function plotter.

9. Equipment modification:

Broader range of test variables, i.e., 0 - 1000°F, 60 - 3200 rpm, and 0 -352 pounds. Also provision for controlled atmosphere.